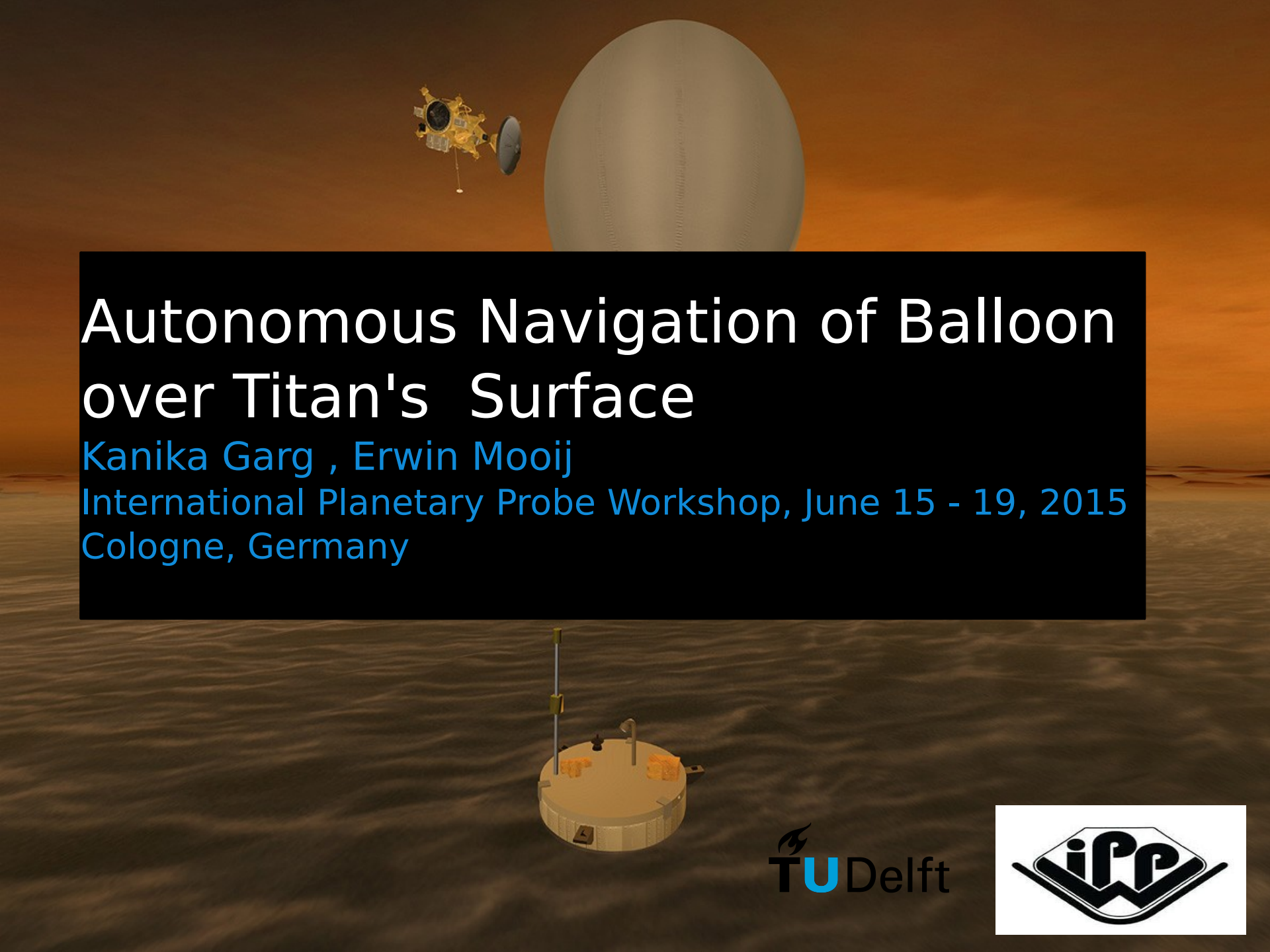


Autonomous Navigation of Balloon over Titan's Surface

Kanika Garg , Erwin Mooij

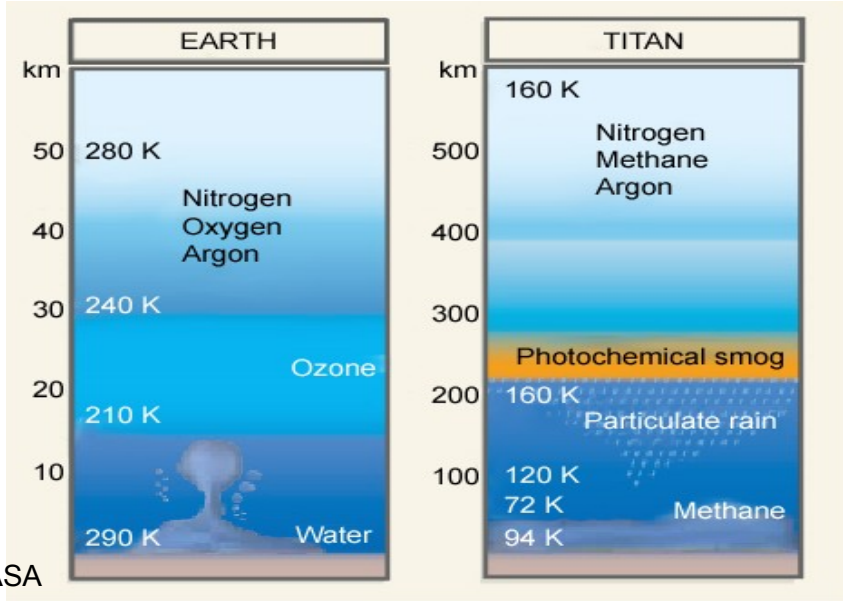
International Planetary Probe Workshop, June 15 - 19, 2015
Cologne, Germany

Why Titan?

Similarities of Titan and Earth

- Atmosphere, structure, composition, greenhouse properties, climate similarities (haze ⇨ ozone)
- Many geological similarities (liquid bodies, fluvial networks, dunes, (cryo)-volcanism, mountains, tectonics, erosion, impact craters …)
- Ice on Titan ⇨ rock on Earth
- Methane cycle ⇨ water cycle
- BUT : Still to be fully understood!!

In addition: an organic chemistry with many similarities with the early Earth's prebiotic chemistry



Source: NASA

Future Missions to Titan

Understand geological System:

What are the processes of liquid cycles and recharging mechanisms and their relation to cryo-volcanism, tectonics and erosion?

Understand surface composition:

What is the composition of surface and subsurface material?
What is the nature of chemical alteration processes?

Understand Atmosphere:

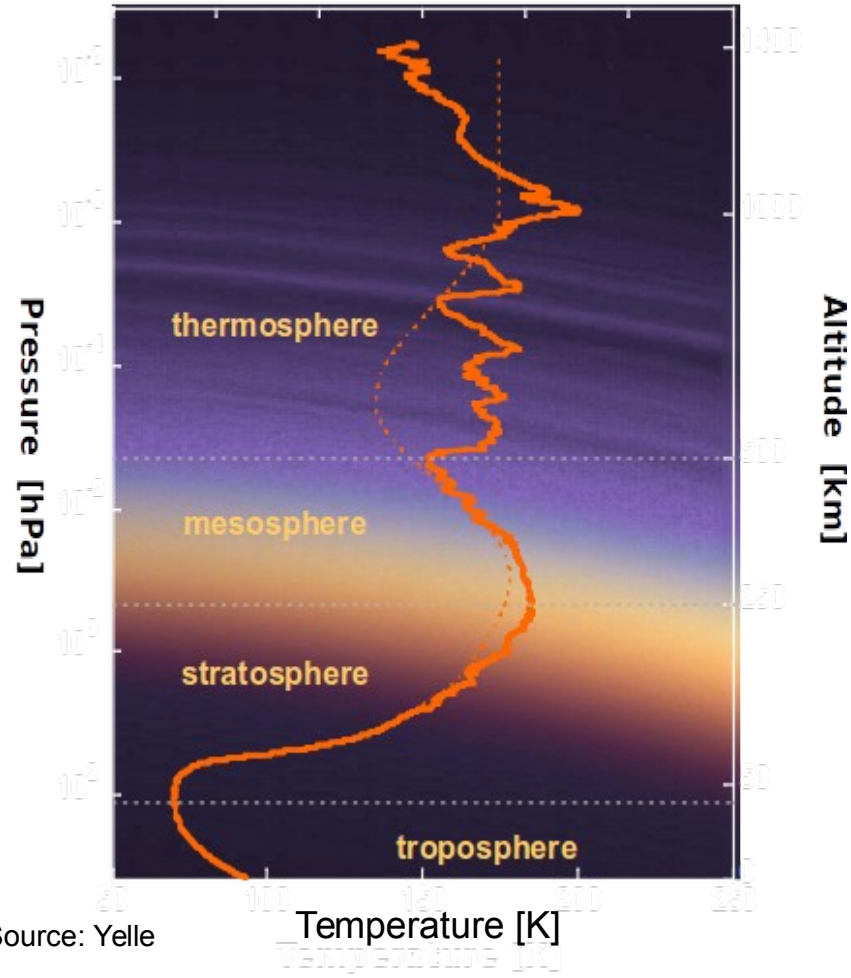
What are the seasonal- and longer-scale dependencies of the distribution of materials across the surface? What is the long-term history of dunes?

Understand liquids:

Are the “lakes and seas” filled with methane and ethane, and do they extend to a subcrustal hydrocarbon “methanofer” system over a larger area of Titan?

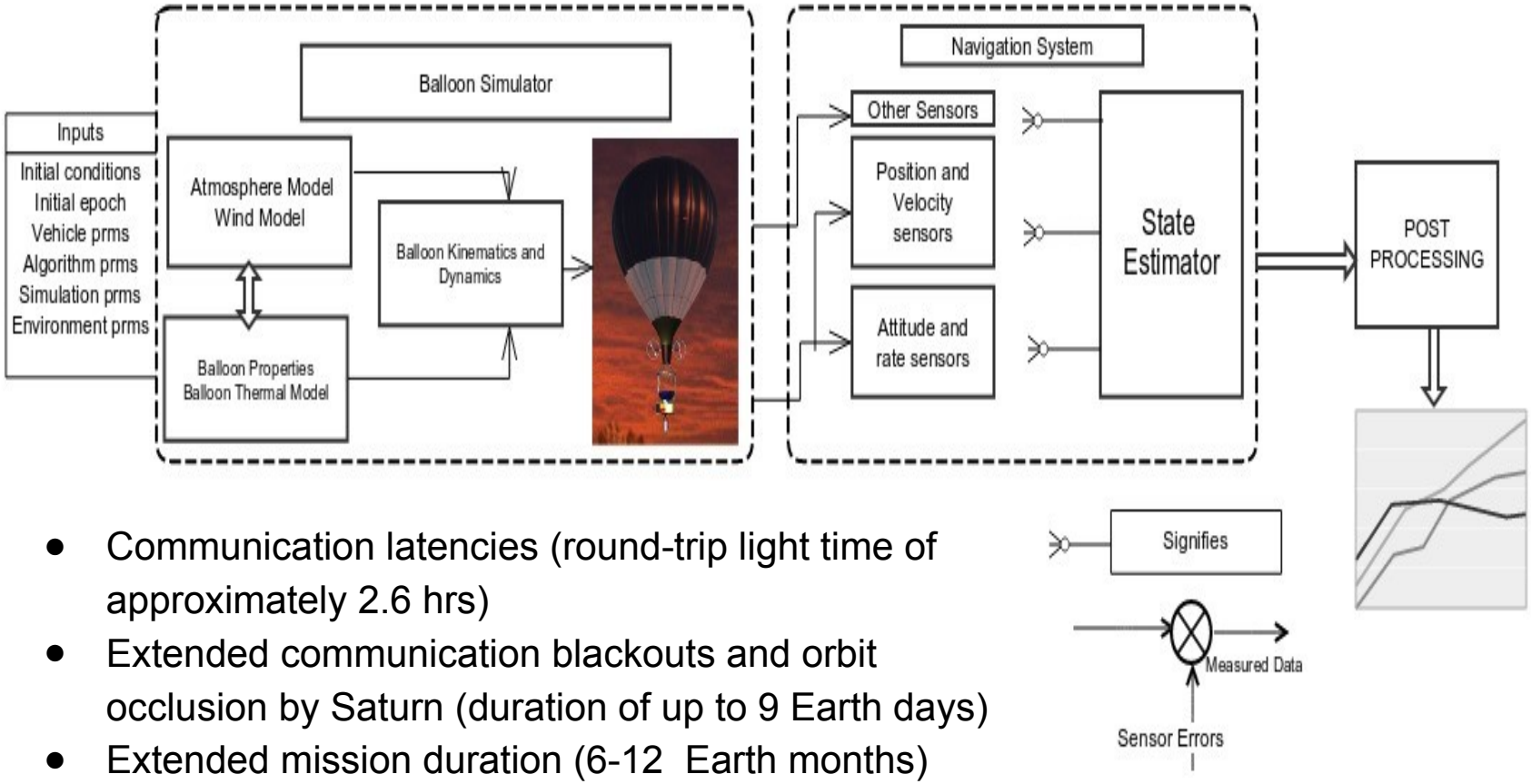
Why Balloon?

- The dense atmosphere (4.5x higher than on Earth) allows for large payloads carried by compact vehicles.
- The atmosphere is clear below 10 km allowing for high resolution imaging.
- Huygens measured very low wind speeds near the surface, allowing for slow overflights and/or station-keeping by self-propelled aerobots.



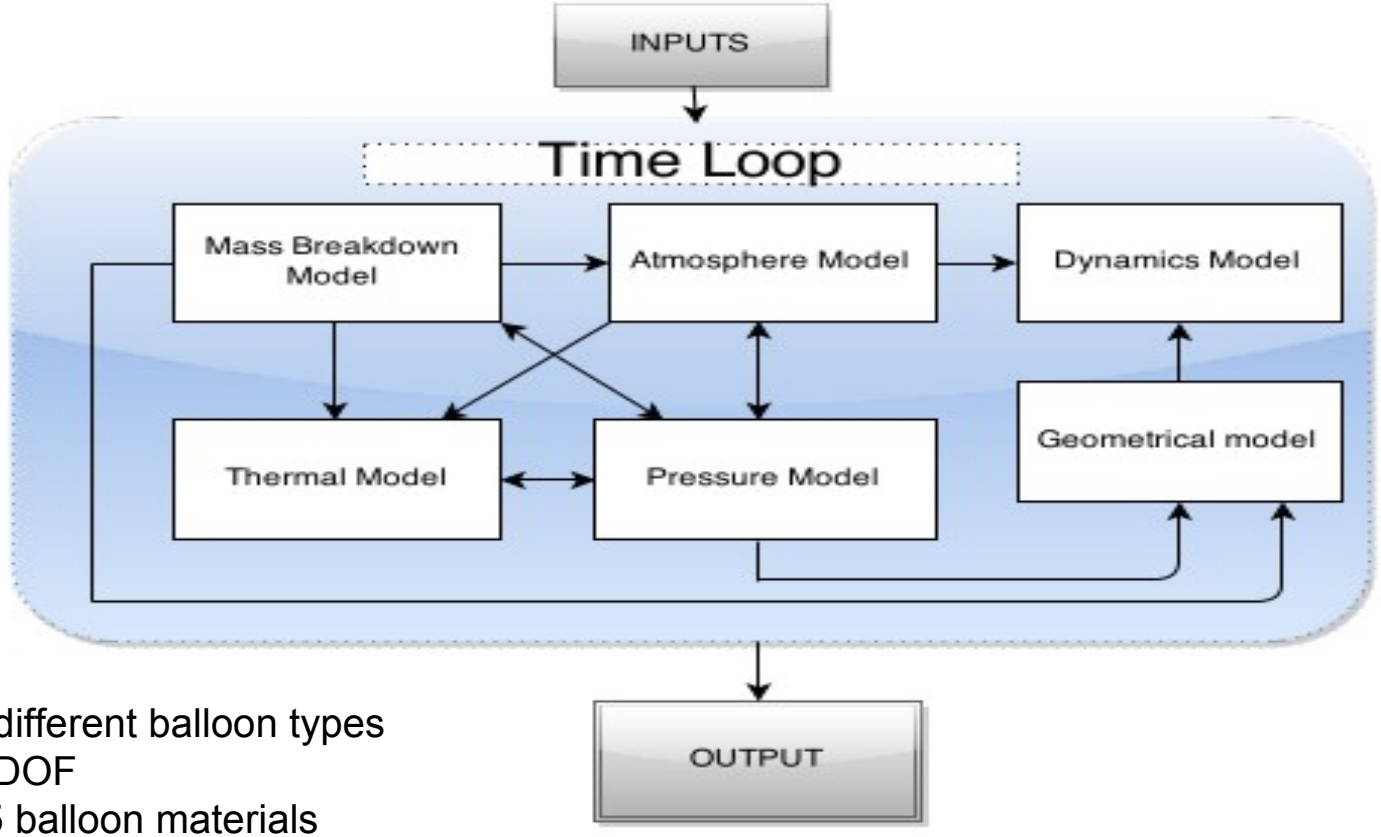
Source: Yelle

Why Autonomous Navigation?



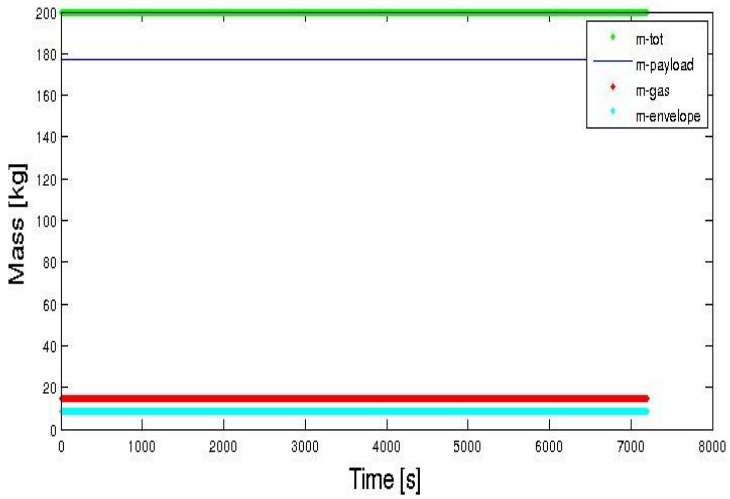
- Communication latencies (round-trip light time of approximately 2.6 hrs)
- Extended communication blackouts and orbit occlusion by Saturn (duration of up to 9 Earth days)
- Extended mission duration (6-12 Earth months)
- Operation in a substantially unknown environment

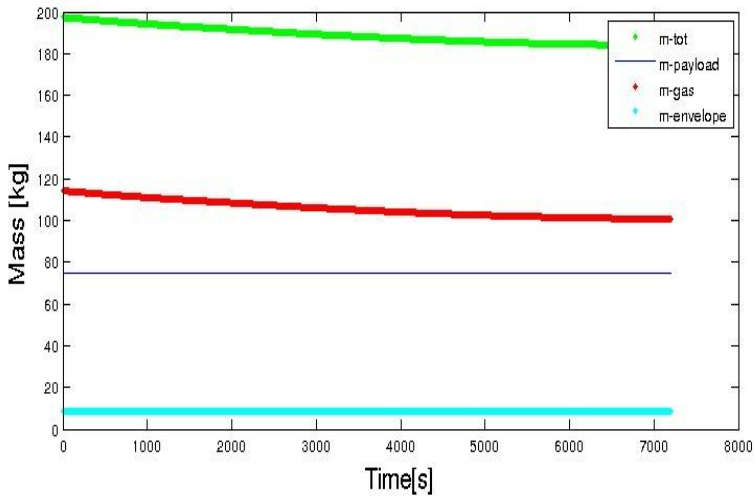
Balloon Simulator



- 3 different balloon types
- 3 DOF
- 15 balloon materials
- Yelle atmosphere + TitanWRF winds
- 2 thermal models
- 3 geometric shapes

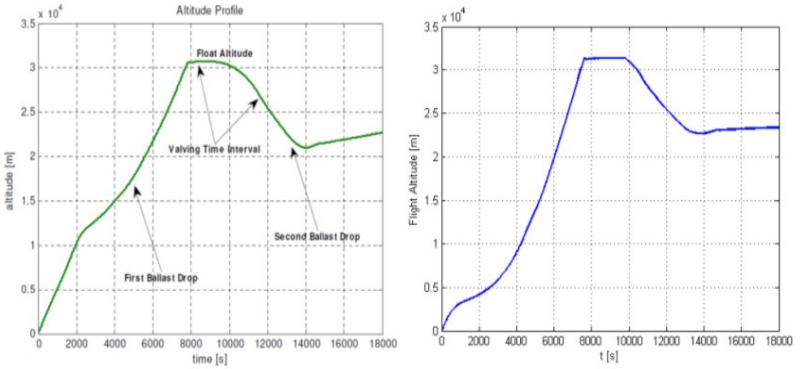
Which Balloon?



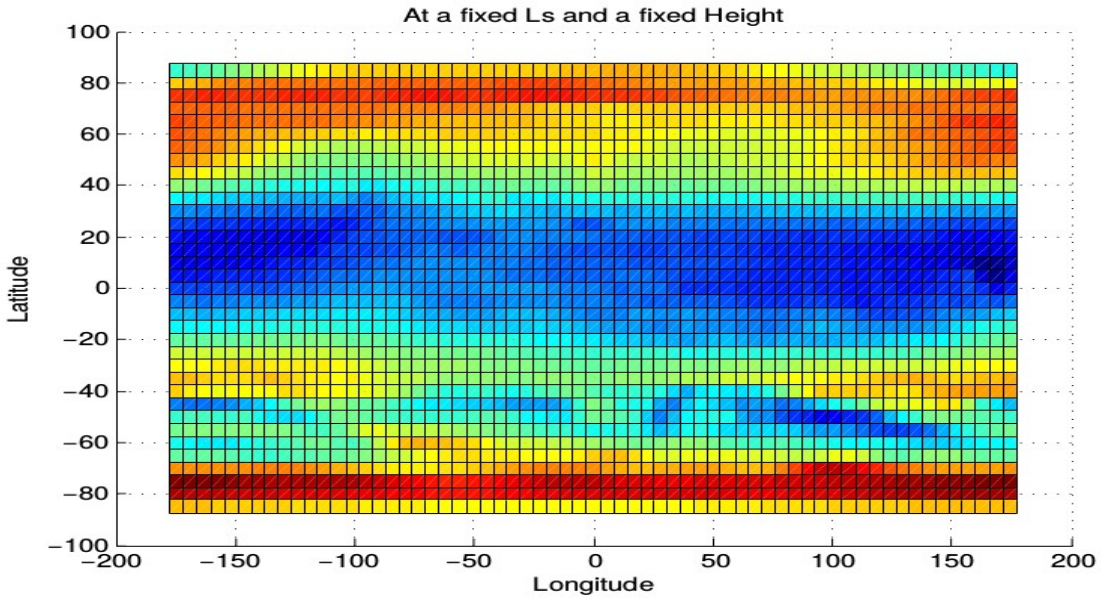


(a) Super-pressure Balloon (b) Hot-air balloon

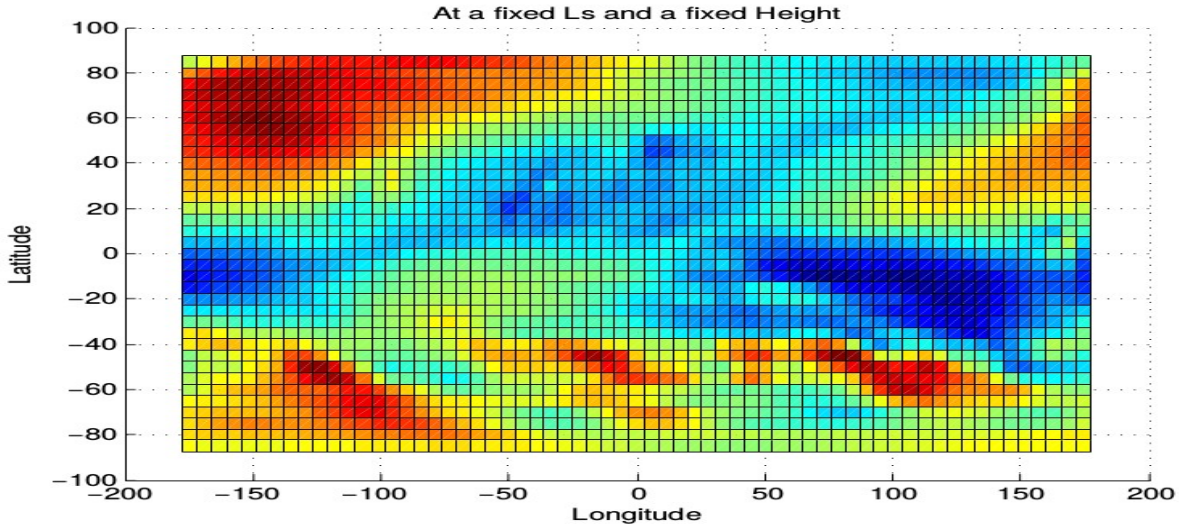
- Size of hydrogen balloon is 4 times less.
- MMRTG not required for hydrogen balloon, but for 6 months operation,1.4kg extra gas is required.
- Time required to fill hydrogen balloon is less than half that of Montgolfier.



Simulator verification using Earth balloon data



Zonal & Meridional winds at 10 km for 314 Ls



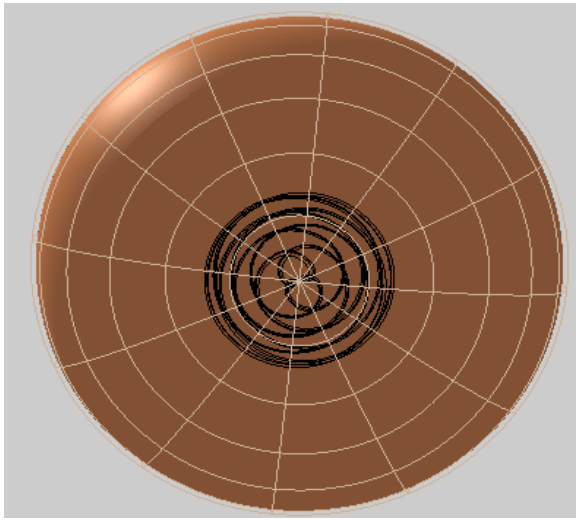
Winds on Titan

- Winds are simulated for year 2035 using data from TitanWRF.
- Winds were simulated for different Ls~304-333 and were found to be more or less the same.
- Model does not account for the effects of surface topography

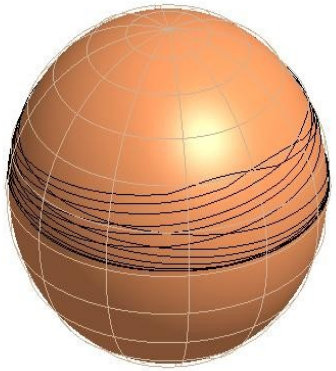
Red: 1.0 m/s
Yellow: 0.50 m/s
blue: 0.25 m/s

GCM data was provided by Dr. Claire Newman from Ashima Research Centre

Balloon trajectory in presence of winds

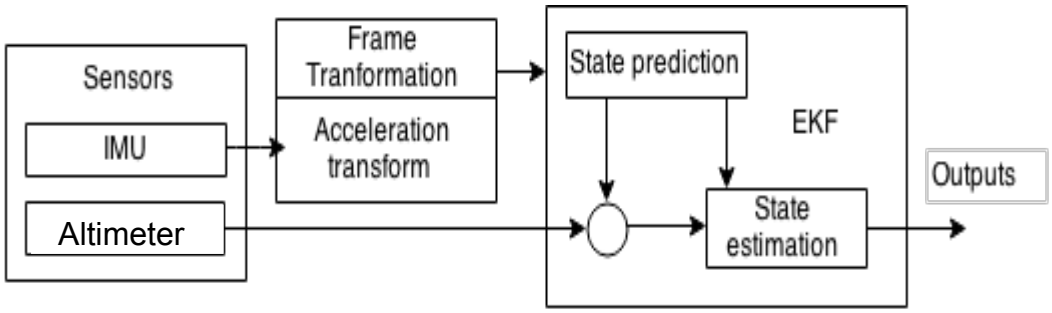


- Balloon deployed at 80 deg latitude and 100 deg longitude.
- It stays near the poles almost entire time.
- The patterns are the result of high speed gusts, but balloon movement is primarily restricted from East to West.



- Balloon deployed at 0 deg latitude and 100 deg longitude
- Circumnavigates Titan number of times, but stays within 0-30 deg latitude.
- No wind gust during this period that can push balloon towards the pole.

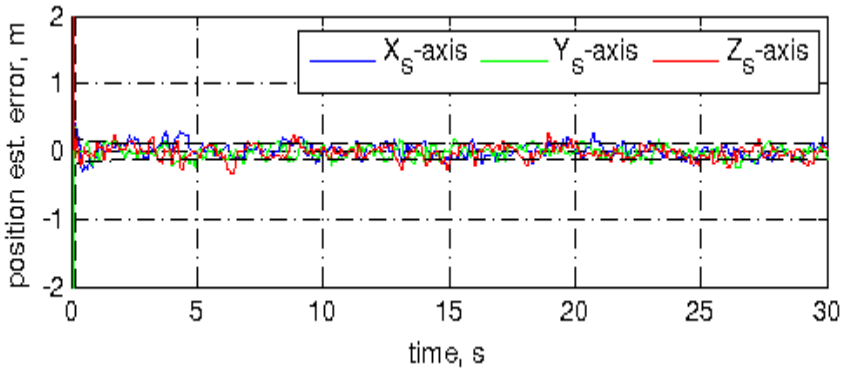
Autonomous Navigator



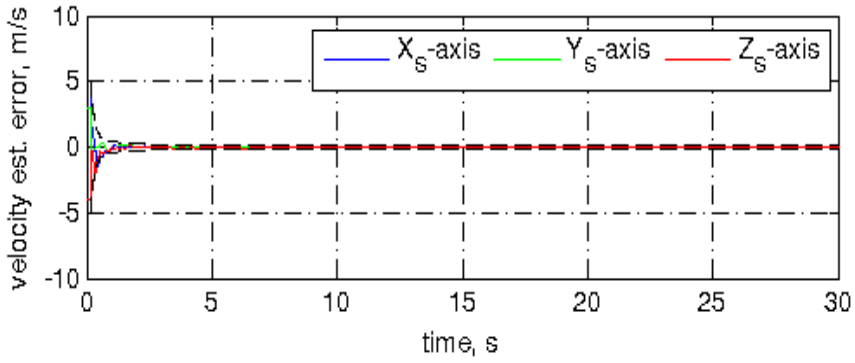
Implementation of Navigation system

- Two filters have been selected (EKF, UKF) for the autonomous simulator.
- EKF is designed and its performance will be compared with UKF later.
- Seven different sensor combinations have been studied(wind anemometer, inclinometer, compass, altimeters, IMU, and NavCams).
- Accelerometer & altimeter are used in the simulator.

Results

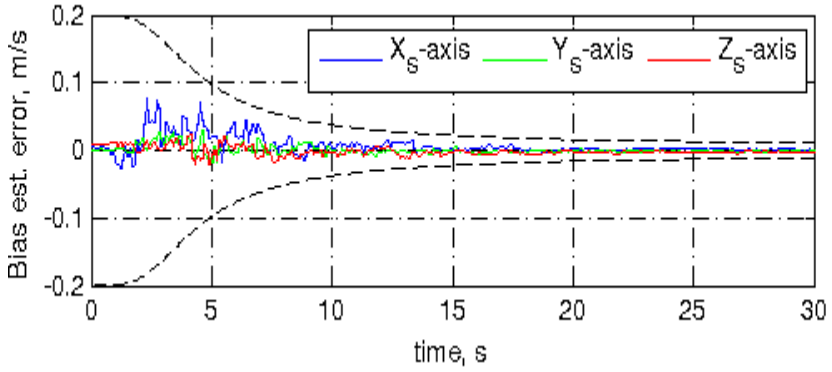


Position



Velocity

- Scale errors and misalignments can be determined with a 90% accuracy in pre-flight tests
- The maximum error that the system encounters in position estimation is 0.2m, and for velocity estimation, it is 1 m/s.
- For long-duration flight, filter has to be re-initialized regularly



Bias

Conclusions

- Super-Pressure balloons are recommended for deployment on Titan.
- Balloon movement is primarily dominated by the presence of winds.
- Absolute navigation of balloon not possible until there is 3D surface model of Titan's surface.
- Accelerometer and altimeter along with EKF provides position estimation of fairly good accuracy.

Future Work

- Comparison of EKF with UKF
- Fusion of more sensors and use of visual navigation.
- Use of guidance algorithm

Source: NASA

Questions?